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Photonic Generation of Millimeter Wave in Radio-over-Fiber Transmission System

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Abstract*: *The advancing communication networks provide favorable circumstances for photonic technologies for achieving the requirement of high data rate and reduced latency. The optical fiber link which is the backbone of almost all communication network has introduced the Radio over Fiber(RoF) technology, in which the mobile front hauling comprises of two domains say, wireless and wired networks. Millimeter wave spectrum usage is one of the evolved technologies for the next generation communication network in wireless domain. Millimeter wave technology integrated with a ROF system is one of the promising technologies that could provide seamless connectivity with high data rate and reduced latency. The integrated system provides the advantages of both optical fiber links and the millimeter wave frequency spectrum. The photonic generation of the Millimeter wave(MMW) signal in MMW-ROF transmission system is a predominant process. In MMW-RoF, conversion of an optical signal to an extremely high frequency radio signal by utilizing photonic up-conversion scheme is done. Thus obtaining the photonic generation of millimeter wave. The study compares the MMW- RoF link with two different optical modulation schemes.

Index Terms: Millimeter-wave, Optical, Photonic, Radio-over-Fiber.

I. INTRODUCTION

The next generation communication network is expected to provide high data rate with reduced latency. To meet these characteristics the wireless technologies have emerged with various technologies such as Coordinated Multipoint (CoMP) Transmission, Distributed Antenna System (DAS), Millimeter wave(MMW), Software Defined Radio(SDR), Software Defined Network(SDN), Cognitive Radio(CR). The simultaneous existence of the various technologies in the communication networks makes the a heterogeneous network[1].The optical technologies have also evolved in parallel with the wireless technologies. Radio-over-Fiber transmission system is one of the proposed technology for the next generation's heterogenous network. Millimeter wave Radio over Fiber(MMW-RoF) is an integrated technology of wireless and wired technologies. MMW-RoF transmission system will have the benefits of using both extremely high frequency and optical fiber for the transmission of the signal.

The RoF transmission system mainly consists of three sections namely, Central Station (CS), Base Station (BS) and Optical Distribution Network (ODN) [2] or Optical Fiber Network (OFN)[3]. All complex processing of the signal is carried out in the CS and simple Optical to Electrical and Electrical to optical conversion occurs in the BS[4]. ODN or OFN is the optical fiber link system used for the transmission of the signal in the RoF transmission system. Fig.1 shows the RoF system topology described by Zin[4]. The radio frequency signal is fed as the input signal and it is optically modulated using an optical modulator and a continuous wave laser source. The signal is transmitted through optical fiber. At the receiver end, optical signal is demodulated and converted to electrical signal using a photo detector. Thus the radio frequency output signal is obtained.

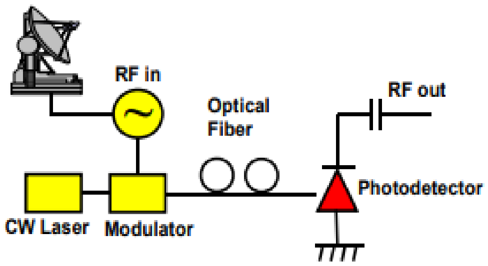

Fig.1. RoF system topology by Zin[4].

The Millimetre wave (mm-wave) consists of a spectrum of extremely high frequencies (EHF) ranging from frequency bands of 30GHz to 300 GHz[6]. A broad range of spectrum can be allotted to the MM wave band. Additionally, MM waves are able to provide high data rates up to 10 Gbps and its spectrum allocation can be co-ordinated worldwide. The MM waves are capable of generating high bit rates and provide worldwide coordination on spectrum allocation as compared to microwave ultra-wideband (UWB) technology[7]. The range of coverage does not dynamically change for MM wave signals. International harmonisation for MM waves is possible and it establishes the necessary condition for a wider application of MM wave signals.

MM wave bands have been proposed for a high capacity wireless systems employing ROF technology. According to Beans [8], the frequency around 60 GHz attracts global telecommunication's interest. This global attraction is primarily due the reason that the frequency coincides with the oxygen peak levels, i.e. the frequencies have high atmospheric attenuation exceeding 15DB/Km.

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High attenuation allows the reduction in the cell size (picocells) [5] and frequency reuse distance in cellular systems. Therefore, this factor increases the wireless capacity. Also, The frequency range opens the opportunity for the world-wide standardization and commercial production. In North America there is 7 GHz of unlicensed spectrum which overlaps with the unlicensed spectra of around 60 GHz in Europe, Japan and Australia. The overall performance of an ROF system must consider the performance of CS,BS and ODN. The advantages of both optical fibers and extremely high frequencies (EHF) are combined to form the Millimeter Wave frequency ROF transmission systems. The Millimeter Wave frequency ROF transmission systems are designed to build an efficient transmission system that supports high data rates. MM wave bands have been recently proposed for a broadband wireless systems employing ROF technology[5]. The Fig.2 describes an overview of subsystems of the RoF link[12]. The extremely high radio frequency carrier wave is optically generated and is referred to as the photonic generation of millimeter wave. This optical carrier is utilized for optical data modulation of the transmitter data. The optically modulated data is transmitted through fiber-optic channel and the signal is detected at the receiver end. The detected signal is converted to electrical signal and the millimeter wave frequency signal is transmitted through the wireless channel.

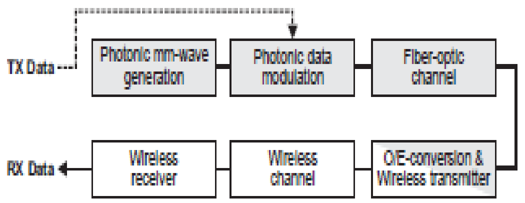

Fig.2. Block diagram of RoF subsystems described by Weiβ[12].

The primary concern in the architectural design of telecommunication network is the design execution of an practically feasible, less complex and cost-effective network. The ROF systems essentially require to be designed with a reduced cost and lesser operational complexities of the individual subject item which is CS, BS and ODN. The requirement of the high speed optical components, complex MM waves generating techniques and larger number of BS are the major drawbacks of ROF systems that has to be taken into consideration. The optimal design of ROF should be such that the simpler design systems.

Fiber Bragg Grating[FBG] is used for extraction of light wave carrier from the received downlink signal and the extracted signal can be reused for the uplink transmission[11]. The first RoF design proposed by Al-Dabbagh [11] for mm-wave generation is using phase modulator and the results are compared with the design outcomes of the RoF using Mach Zehnder (MZ) modulator for optical modulation.

II. METHODOLOGY

A. *RoF using Phase Modulator*

The design proposed by Al-Dabbagh [11] using phase modulator is shown in Fig.3. The full-duplex mm-wave RoF network is composed of the central station (CS) and the base station(BS). BS is also referred as Remote Antenna Unit (RAU). The CS is comprised of a directly modulated laser source, a phase modulator and the uplink receiver. The phase modulator is driven by RF sinusoidal signals of the local oscillator. For downlink, the signal is propagated through a single mode fiber(SMF). After the transmission through fiber, the received optical signal is then filtered in the BS and then amplified. FBG is used for the reuse of the optical carrier in the uplink transmission of the signal[11].The reflected optical carrier, which passes through the FBG, will then be applied to the optical modulator and thus produce the required optical mm-wave signal for the uplink transmission. The photonic generation of millimeter wave is obtained with the aid of a directly modulated laser, phase modulator and the local oscillator in the downlink and using FBG and phase modulator in the uplink.

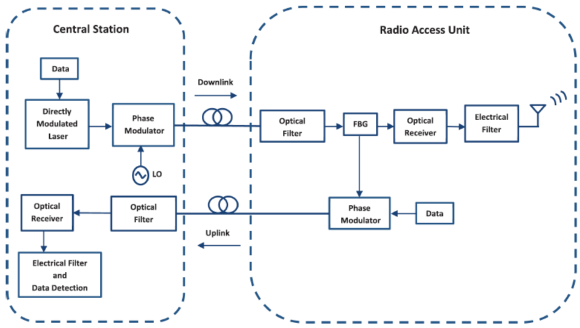

Fig.3. The block diagram of a full-duplex RoF with photonic generation of mm-wave proposed by Al-Dabbagh[11].

The simulation layout for the downlink transmission implemented using Optisystem15[9] is shown in Fig.4. Pseudo random bits are generated using a generator and corresponding pulses are obtained using the NRZ pulse generator. This pulse is fed to a directly modulated laser, thus obtaining an optical data signal. This optical signal is modulated using phase modulator to which an extremely high frequency signal is fed as a carrier from a local oscillator. In the layout 64GHz is given as the local oscillator output frequency. The data is transmitted through optical fiber.

At the receiver end, the received signal is filtered using a Gaussian filter and the filtered data is amplified using an optical amplifier. The amplified signal is filtered using an optical filter FBG[10], which extracts the 1550nm carrier frequency from the data signal. The resulting filtered photonic millimeter wave data signal is fed to a PIN photo detector. The optical signal is converted to electrical signal and thus the required output is obtained.

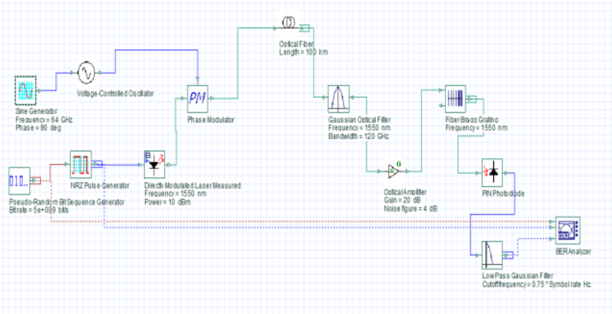

Fig.4. Layout of Downlink transmission using phase modulator.

The resulting eye diagram obtained from the BER Analyzer is shown in Fig.5.The distance of transmission of the signal is 100Km. The process is followed by the transmission and reception of the mm-wave wireless signal to and from the user terminal by operating an antenna.

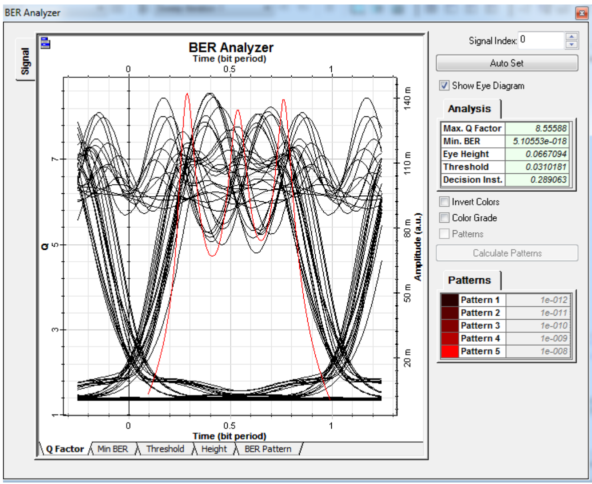

Fig.5. Eye diagram output obtained using Phase modulator.

B. *RoF using Mach Zehnder modulator*

The full-duplex mm-wave RoF network design proposed by Al-Dabbagh[11], transmits using a phase modulator, which can be replaced by a Mach Zehnder(MZ) modulator as in Fig.6. The photonic generation of millimeter wave is obtained with the aid of a continuous wave laser, Phase modulator and sine wave generated using a sine wave generator and the voltage controlled oscillator.

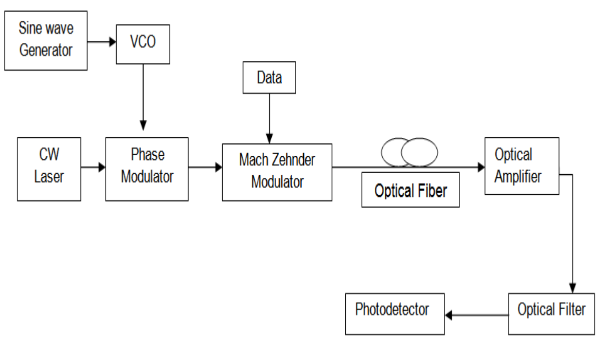

Fig.6. A block diagram of mm-wave photonic generation using Mach Zehnder Modulator.

The simulation layout of the photonic generation of millimeter wave and the data transmission using Mach Zehnder , simulated using Optisystem 15 is shown in Fig.7. In the design layout, the bits are generated using a Pseudo random bits generator and its corresponding pulses are obtained using the NRZ pulse generator. The generated 5Gbps pulse are fed to a MZ modulator. The photonically generated millimeter wave is obtained from the phase modulator output. The output from phase modulator is fed to MZ modulator, after boosting the signal using an erbium doped fiber amplifier(EDFA), for optically modulating the data signal. The data signal is superimposed on the photonically generated signal, thus obtaining an optically modulated data signal. The data is transmitted through optical fiber.

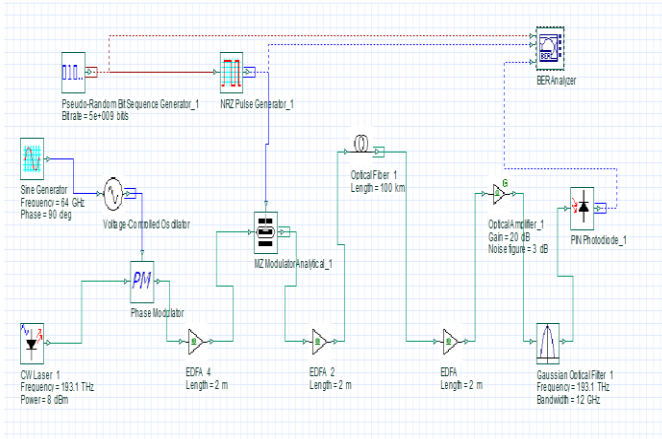

Fig.7.Layout of downlink using Mach Zehnder modulator.

At the receiver end, the received signal is amplified using Erbium Doped Fiber Amplifier(EDFA) and is again amplified using an optical amplifier.The amplified signal is filtered using FBG[10], which extracts the 1550nm carrier frequency from the data signal. The resulting, filtered photonic millimeter wave data signal is filtered using a Gaussian filter and the filtered output is fed to a PIN photodetector. The optical signal is converted to electrical signal and thus the required output is obtained. The resulting eye diagram from the BER Analyzer, when transmitted at 100 Km is shown in Fig.8.

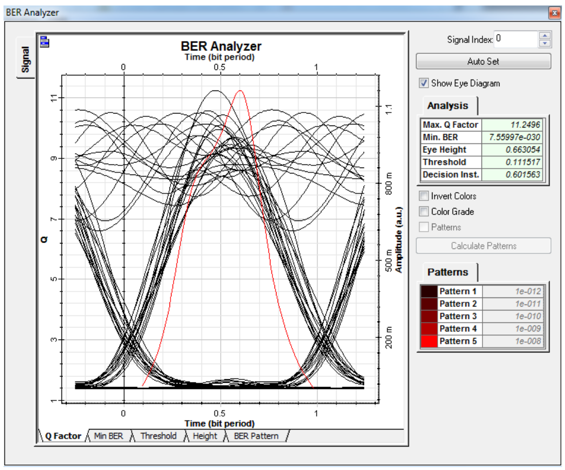

Fig. 8. Eye diagram of downlink transmission, obtained using Mach Zehnder modulator

The two designs have pros and cons concerning the Quality factor(Q Factor), the Bit Error Rate(BER) and Eye Height. Mach Zehnder is with comparatively high Q Factor and Eye height and less minimum bit error rate compared to Phase modulator design. It shows less error in eye diagram for the same data rate , when compared with Phase modulator output. The table comparing the parameter values are given in Table I.

TABLE I. COMPARISON OF MODULATORS PERFORMANCE PARAMETERS

Modulator	Q-Factor	Min BER	Eye Height
Phase Modulator	8.55588	5.10553e-018	0.0667094
Mach Zehnder	11.2496	7.55997e-030	0.663054

III. CONCLUSION

There are many difficult tasks in the designing of MMW-RoF transmission system. Nevertheless integrated technology is a promising technology that can support high data rate and provide seamless connectivity in the next generation communication network. Developing a practically feasible, less complex and cost effective transmission system design for MMW-RoF system is an ongoing research process. There are several transmission media technologies used for broad-band deployment schemes that poses as a strong contenders for the Radio-over-Fiber Transmission Systems.

From the simulation results, it can be inferred that design using phase modulator and MZ modulator gave better performance than the design using phase modulator alone. It gives us an opportunity to develop a MMW-RoF, with photonic generation of MMW using phase modulator and MZ modulator as optical modulator.

A novel design of MMW-RoF with simplicity maintained at the base station will aid the next generation of mobile access networks. It will be possible to develop an MMW-RoF transmission system with less complex photonic millimeter wave generation technique. This system would be designed to meet high Q factor and least BER. There are impairments like jitter in optical fiber communication. Designing a feasible MMW-RoF transmission system with reduction in the impairments according to the application will make the system perform better in the next generation communication networks.

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